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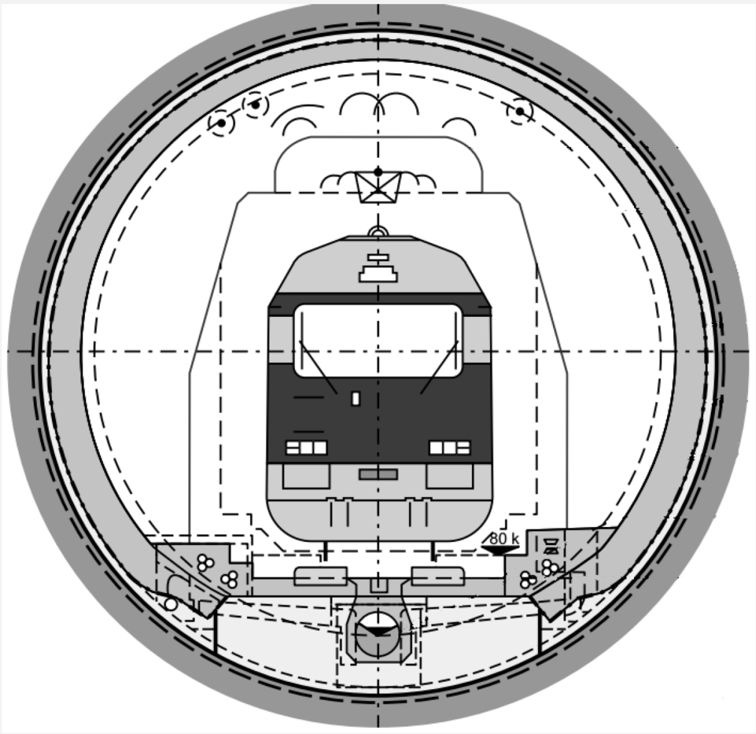
Discrete element analysis of a cross-river tunnel under random vibration levels induced by trains operating during the flood season

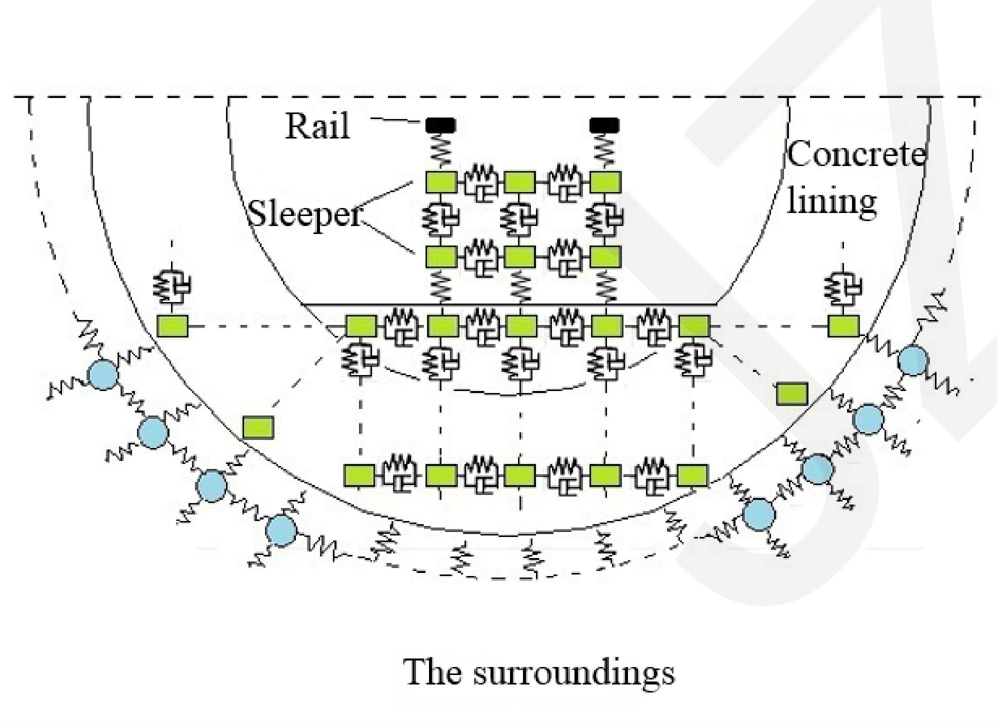
Key words:
discrete element method, cross-river tunnel, water pressure, metro-train operation, random vibration level, acceleration

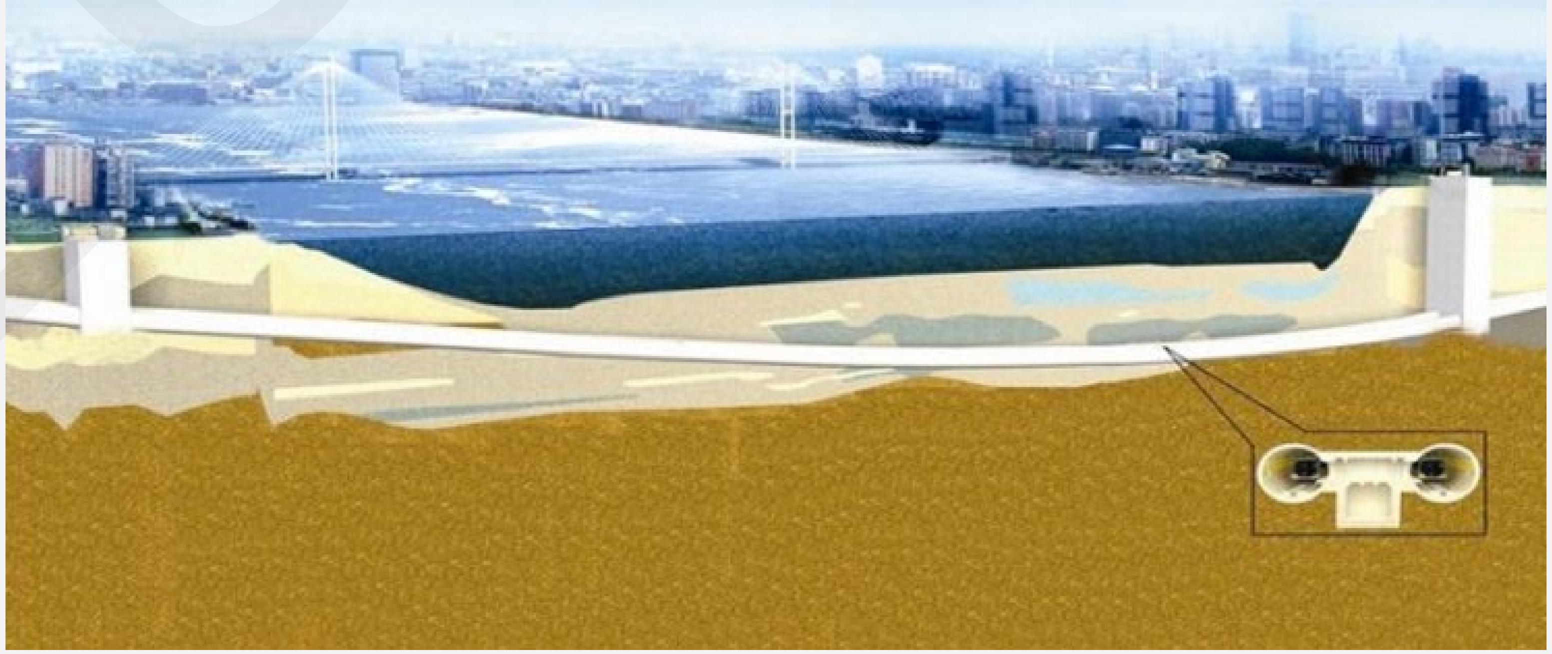


Cross-river tunnel

Constitution and potential damage

- Water pressure: large additional pressure and pore water pressure
- Surrounding soil: low strength and high permeability
- Concrete ling: asymmetric deformation and cracks
- Metro train load: irregular vibration levels and large impact load

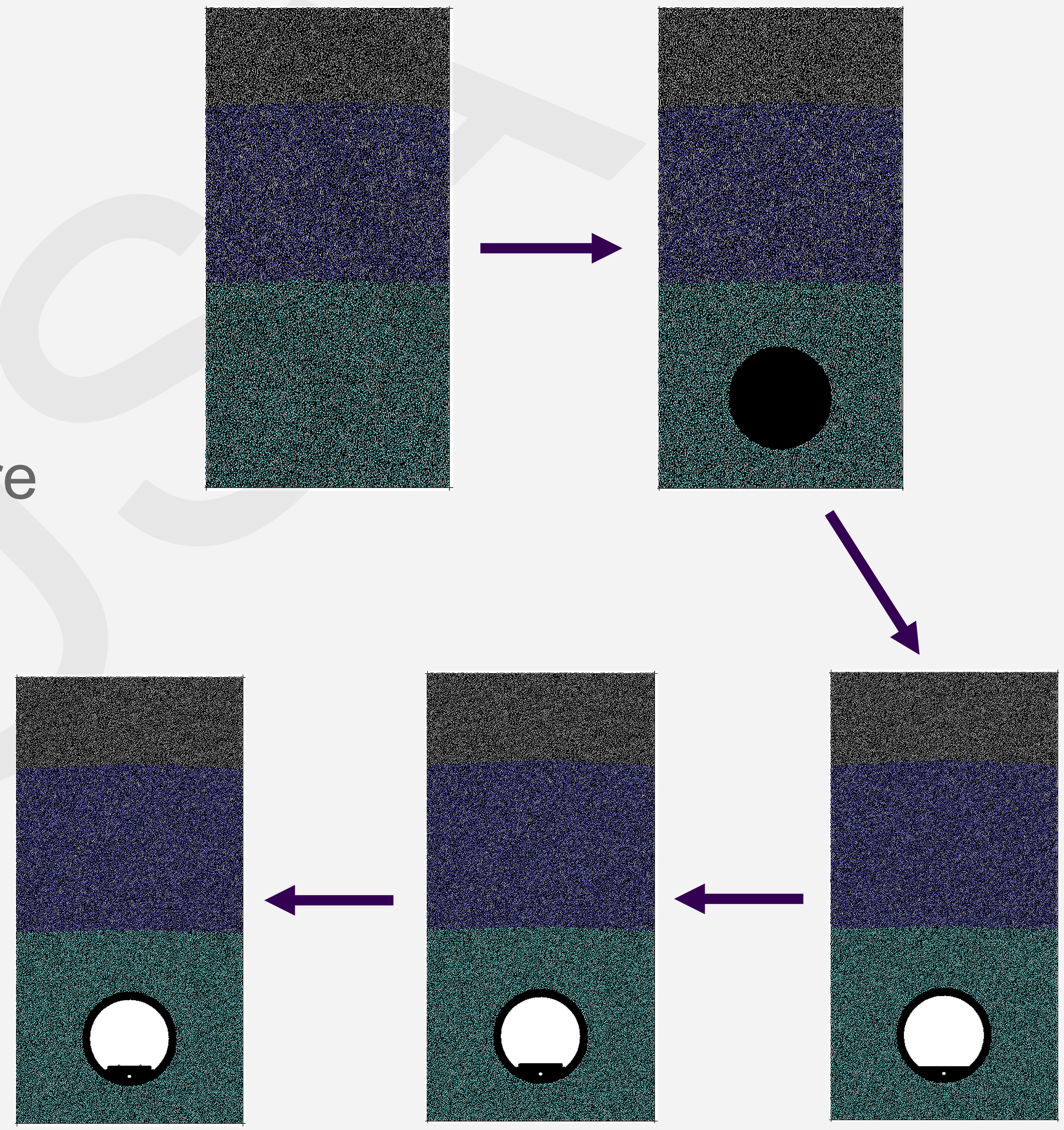




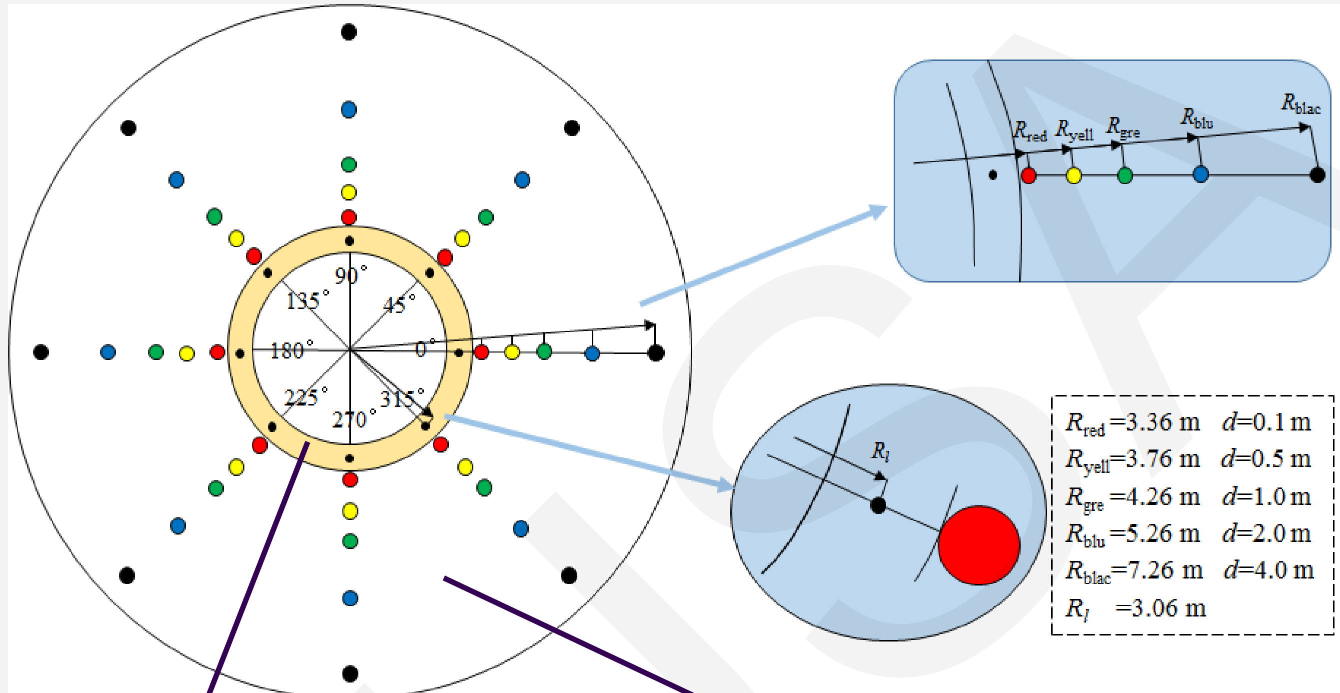
DEM model

Model setup:

- Micro parameters calibration
- Surrounding soil deposit
- Consolidation under water pressure
- Excavation process and concrete lining modelling
- Sleeper modelling
- Rail modelling
- Irregular vibration load execution

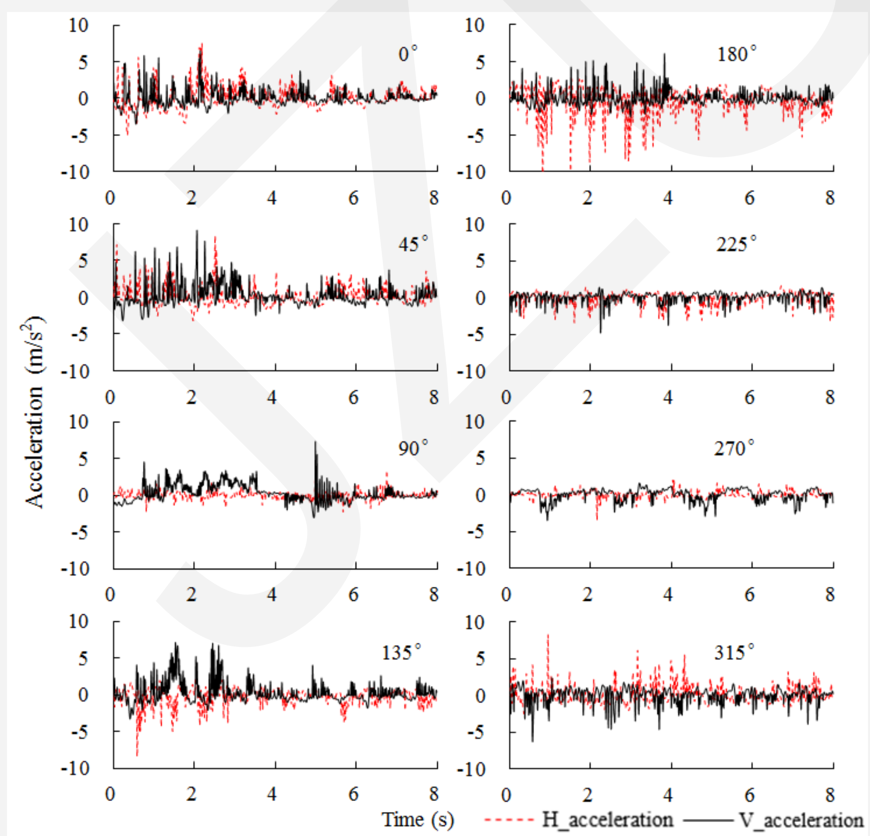


Train load effect under NWP

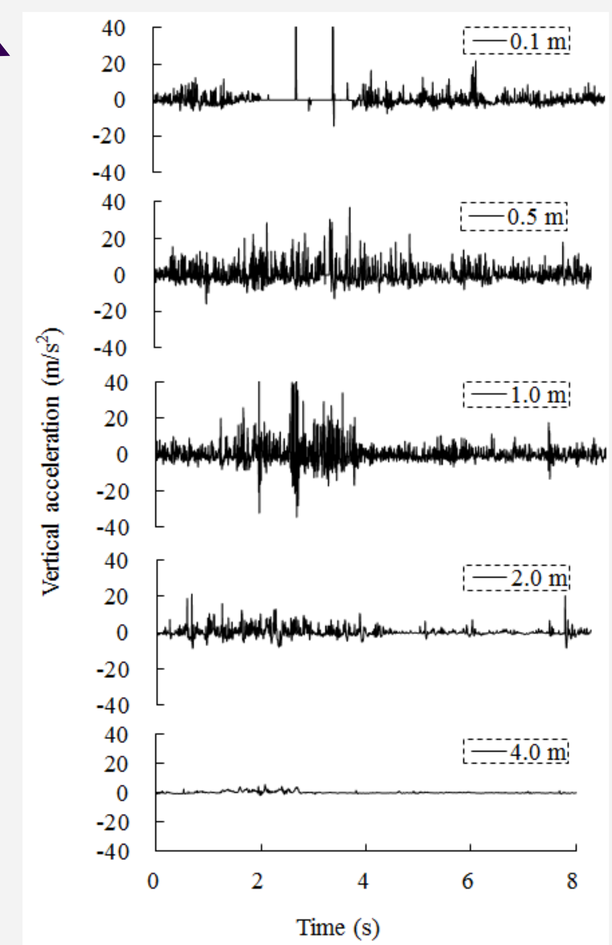


Distribution of measurement circles

The vertical accelerations at angles of 0º, 45º, 90º, 135º and 180º in the upper part of the concrete lining were higher than those at angles of 225º, 270º and 315º in the lower part of the concrete lining.



Concrete lining



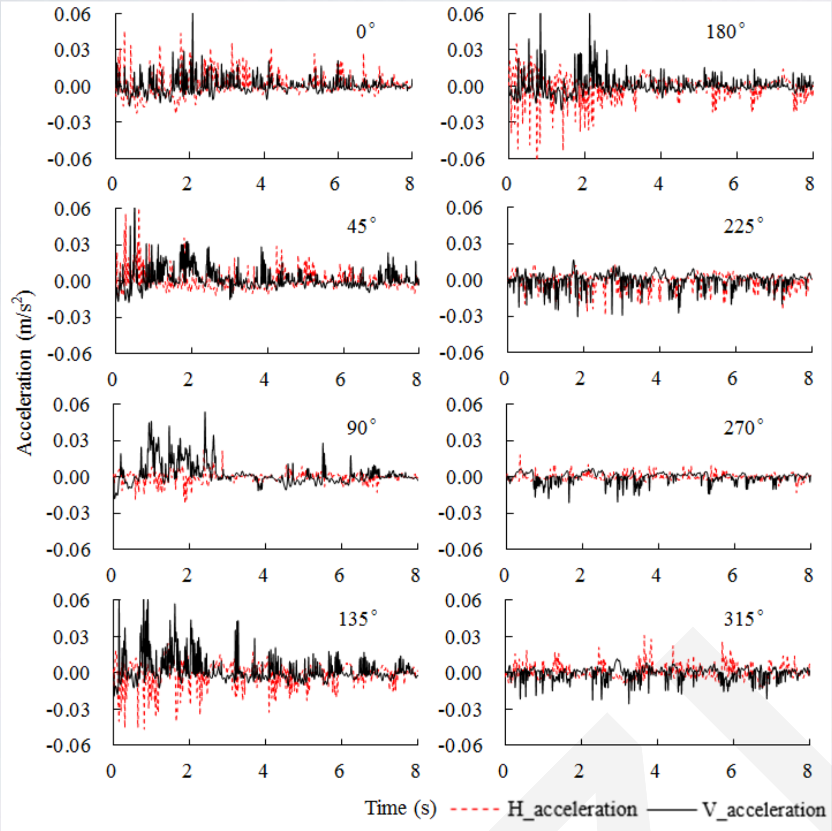
The surroundings

Vertical accelaration increases, then decreases

The kinetic engergy is amplified within a finite distance, then dissipates due to frictional resistance and damping effect

Train load effect under FWP

Concrete lining

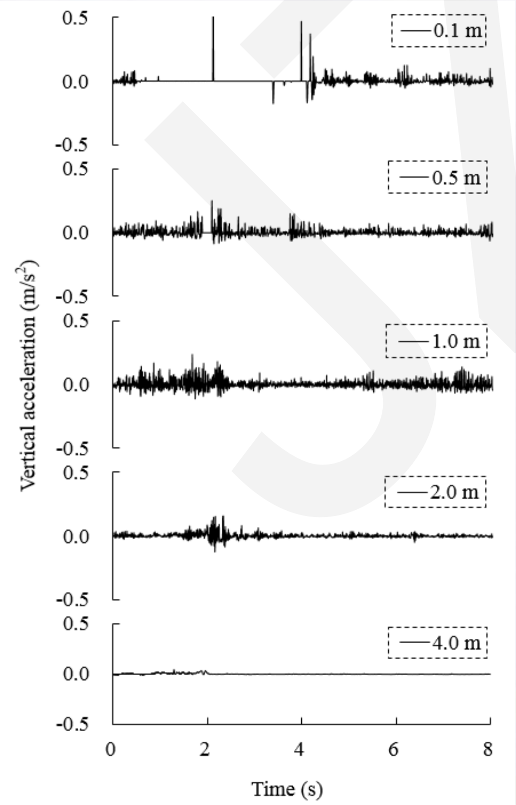


The values of vertical acceleration under FWP were much smaller than those under NWP

Positive acceleration occurs in the tunnel ranging from 0º to 180º
Negative acceleration occurs in the tunnel ranging from 225º to 315º

The sign of these vertical accelerations means that the movements of particles in the concrete lining pointed toward the inside of the tunnel. This is a result of the high confining stress around the tunnel

The surroundings



The accelerations of particles at the vault of the tunnel and the surroundings increased first and then decreased as the distance increased, which is consistent with the results under NWP. The mechanism of the transmission of vibration waves was the same as that under NWP: the vibration waves were amplified. The values of the vertical accelerations, however, were much smaller under FWP than under NWP

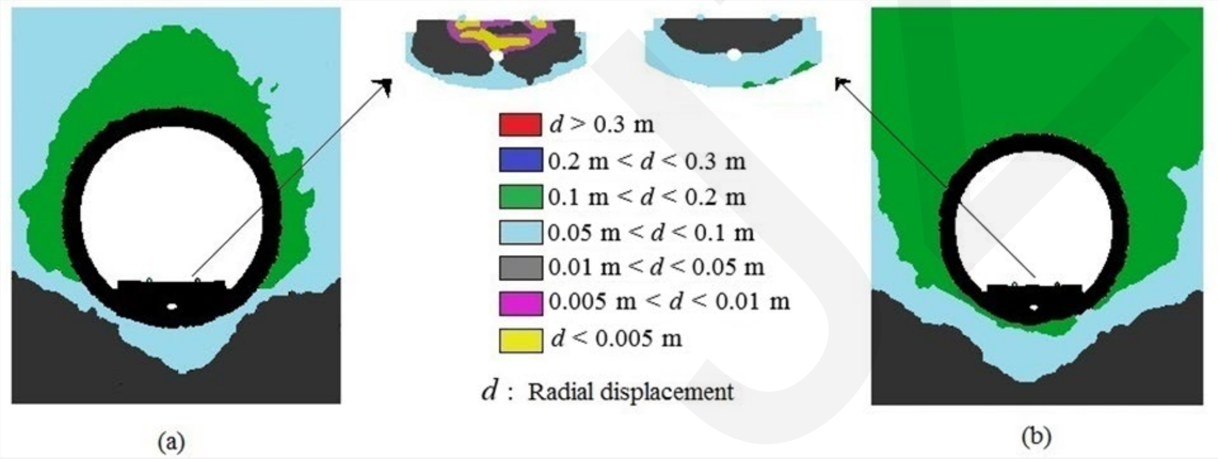
Tunnel deformation under N/FWP

Train speed

- Vertical acceleration of rail increases with train speed increases
- Large impact load executes on the rail
- Higher load frequency, higher vertical acceleration
- Radial displacement in the track foundation decreases with train speed increases

Tunnel deformation

- Large deformation occurs at the vault of the tunnel
- Wider deformation zone under FWP condition
- The disturbance zone in the track foundation decreases with train speed increases



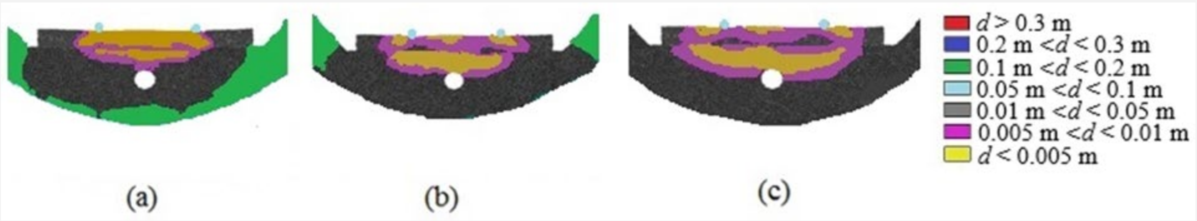


Fig. 22 Radial displacement of the track foundation under FWP after continuous operation of two trains (a) 60 km/h; (b) 80 km/h; (c) 100 km/h

Fig. 21 Radial displacement of particles around the tunnel in this model with a train speed of 40 km/h (a) under NWP; (b) under FWP

Perspectives and Research Priorities

Research Priorities:

- Further study on the influence of different train loads on the cross-river tunnel
- 3D cross-river tunnel model used in train operation
- Dynamic characteristics of the surroundings in fluidization may occur during train operation

The simple model proposed cannot completely simulate the in situ situation, however, it is helpful for the assessment of the safety and stability of the cross-river tunnel during the rainy season. The study of cross-river tunnels, as a main transportation artery in major cities, requires further attention. The DEM has unique advantages for simulating the large deformation of discrete particles. A large amount of work remains to be done, including on the works mentioned above, the design depth of cross-river tunnels to obtain more desirable stability, and on the influence of adjacent metro operations on the stability of existing tunnels.